Design Engineering Practices in Indian Manufacturing Firms: An Empirical Study

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***Abstract* - The design process is a critical component in competitive product development and in the industrial innovation process. The work reported in the paper tries to map the different patterns of design engineering practices as industrial innovation indicators as they occur in firms located within the National Capital Region (NCR) of India representing New Delhi and its surrounding regions and highlights the role of developing suitable indicators to tap specific design engineering practices and the network linkages. The results indicate that majority of firms possessing a separate design department exhibit a better appreciation of what constitutes a successful innovation and follow it up by formulating design engineering agreements with a networked partner simultaneous to marketing, service or R&D arrangements, and also that firms with more open cooperation with the outside research environments almost always have been more technically successful in designing new products.**

Keywords - design engineering; national capital region; India; indicators; industrial innovation.

1. INTRODUCTION

National governments in many countries launch specific schemes in order to promote innovative activities in the manufacturing sectors like providing fiscal incentives for research and development (R&D) and quality control [1, 2, 3]. This is especially true for developing countries like India. Such schemes are often monitored through indicators devised for this purpose.

The significance of the term design, its definition, its conceptual construct, and also the critical role it plays in innovation policy framework, are increasingly being recognized [4, 6, 8, 9, 10]. A very concise definition of design describes it as a creative process by which product innovations and ideas are reduced to an economically viable arrangement, this arrangement being set down on paper as a proper schedule. The concept of economic viability can be expanded to include (i) the economic objective; (ii) a product to meet that objective; (iii) how effectively the product meets the economic objective; (iv) how well the product work; (v) how the product can be made; (vi) hence, how much the product will cost to make; and (vii) what the product will cost to maintain. When a firm moves into new product areas and technologies, and as the firm's competitive context that engineering design has a strong relationship with the management practices being adopted for successful innovation, and plays a significant part in improving the competitiveness of products or firms [4, 5]. Li and Boyle [6] presents review of papers published in the Journal of Engineering Design from 2007-2008 probing the perspectives, challenges and recent advances in engineering design.

The aforementioned discussion clearly brings into focus the imperative and the need to bring design, consciously, within the framework of an innovation policy. A manufacturing firm that seeks to compete effectively in the market needs to formulate and implement innovation-based strategies where design forms an integral part, for instance, in developing new products and in meeting customer satisfaction, but empirical or theoretical research on design engineering practices as indicators of industrial innovation have been few. The work reported in the present paper aims to fill this gap. The study attempts to map the different patterns of design engineering as are being practiced in the firms located within the National Capital Region (NCR) of India, meaning New Delhi and its surrounding areas. After a thorough review of the literature in the next section, methods employed and the data sources have been explained in the following section. The last two sections deal with the results of the analysis and the broad conclusions of the study, respectively.

2. DESIGN IN THE CONTEXT OF INDUSTRIAL INNOVATION

When a firm moves into new product areas and technologies, and as the firm's competitive context becomes less predictable and more complex, communication between the firm and the world outside will increase. Kalogerakis, Luthje, and Herstatt [7] report a work where in-depth interviews were carried out with project leaders of 18 design and engineering consulting firms located in Germany and Scandinavia in order to probe the links between design innovations and analogies. Other studies have highlighted that engineering design has a strong relationship with the management practices being adopted for successful innovation, and plays a significant part in improving the competitiveness of products, firms or even national economies [8, 9, 10]. In this regard, it

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could be pertinent to mention that a special issue of the International Journal of Production Research on data mining applications in engineering design, manufacturing and logistics was brought out in the year 2006 [11]. There is also the issue of outsourcing the engineering design process by a firm. The limits of design and engineering outsourcing in product development, and the sources of these limits have been a subject of debate [12]. About 100 research papers and 30 commercial systems/international standards launched have been reviewed in terms of underlying algorithms, mechanisms and system architectures with a view to focus on research being carried out to develop methodologies and technologies to support geographically dispersed teams to organise collaborative design based on the quickly evolving information technologies [13].

The role of design engineering becomes very critical in cases where the project requires too advanced a technology and/or the transition to manufacturing is complex and requires very large scale-up. This is typically true for technology transfer agreements from the national R&D laboratories to the industries. The products and the processes are found to be most satisfactory in the bench-scale on lab-scale work but in the commercial scale operations, these often fail to live up to the expectations and the innovative efforts might lead to a failure [14, 15, 16, 17]. The issues raised, therefore, focus on identifying appropriate customers and working closely with them [18].

Other studies have highlighted the significance of design in the innovation process and the criticality of recognizing the same. By focusing on the environmental impacts of the electronics industry, the perspectives for design for environment have been debated [19]. In a separate study of 203 new products - both winners and losers that were launched into the market place - three hypothesized factors, all of them directly or indirectly related to design were found to be most significantly related to design new product success [20]. The factors were (i) product advantage (ii) proficiency of predevelopment activities, and (iii) protocol, including product concept, specifications and requirements. Among recent works in the Indian context, a case study was carried out in an Indian manufacturing organization for probing the role of computer aided design and engineering as enablers of agile manufacturing [21]. In the same vein, engineering firms in Thailand have been probed to propose a decision support methodology for the development and application of product eco-design, with special reference to their use in these firms [22].

Information about the user's needs helps to clarify the firm's activity. A firm that has achieved a through understanding of the needs of the buyer can use the knowledge to guide innovative effort. A firm that faces a technology adoption decision engage in an extension effort reduce uncertainty associated with that decision [23], and information about the buyer is an important part of this exercise. In situations where the clarity of innovation objectives is higher, the firm is expected to be more willing to engage in innovation. The information-seeking networks of marketing managers are closely tied to sources that clarify the customer's needs. When a firm moves into new product areas and technologies, and as the firm’s competitive context becomes less predicable and more complex, communications between the firm and the world outside will increase [24].

It has been observed that one of the most important factors affecting the competitiveness of American manufacturing sectors is the long-standing neglect of engineering design [25]. The authors assert the following: (i) in terms of long-range strategy, the factors of cost, quality and time-to-market are design problems more than manufacturing problems; (ii) market loss by US companies is due to design deficiencies more than manufacturing deficiencies; (iii) manufacturing process themselves are designed; (iv) many technical problems commonly associated with manufacturing process are traceable to design problems; and (v) opportunities to surpass foreign competitors are best found in engineering design. Spitas [26] has reported a work carried out through a questionnaire-based survey of design engineers to evaluate the industry’s perception and use of systematic design paradigms.

As already mentioned, a particular new product failure might act as the seed for the germination of successful redesigned product. The design process is an important stage in new product development. Based on graph theory and the weighting concept, a quantified design structure matrix (a systematic planning method of optimizing design priorities and product architecture for managing product variety from an informational structure perspective) has been presented in the literature [27]. In another study, the relationship between different retail channel structures and channel strategies (for instance, an exclusive channel strategy) and the engineering design of a new product, conditional on consumer preference distributions and competitor product attributes have been examined [28]. Even other researchers have emphasized that by and large designs are modifications from previous products and lessons learned from earlier designs can be beneficial when developing new products [29]. Based on the example of a new generation of diesel engine design, the authors have shown how the ability to predict change propagation can guide designers through conceptual design allowing them to analyse design alternatives and foresee potential problems arising from the product architecture.

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3. METHODS/DATA

For the study, a stratified sample out of a population of industrial concerns operating within the National Capital Region (NCR) of India has been considered. Data were collected from 53 firms operating within the NCR of varying annual turnover, size and belonging to automobiles, engineering, chemicals/pharmaceuticals/textiles, and electrical/electronics sectors. A questionnaire, formulated on our preliminary understanding of the innovation process, was later modified with inputs from a pilot survey to be used in the later part of field investigations. The responses were subject to detailed analysis in terms of dimensions like design objectives, sources of information, network partners in the design processes, etc.

The analysis has been carried out in various stages to bring out the critical importance of design engineering in industrial innovation, and the factors related to the success of innovative efforts. Category 1 (numbering 23) firms refer to those firms that have a separate design department while Category 2 (numbering 30) firms have no separate design department.

4. RESULTS

Table 1 presents the total value of machinery as a percentage of gross turnover of the firms. Set against the importance of establishing and running a separate design engineering department in a firm, it is observed from the Table that this percentage value is 15.58% for firms with a separate design department that is substantially lower as compared to 33.59% for firms without a separate design department. On a closer examination, it is found that this difference is most conspicuous for small (up to INR 20 million turnover) and very large firms (a turnover of higher than INR 200 million) where 45 INR=1 USD.

Further analysis has been carried out separately for Category 1 and Category 2 firms.

Table 2 presents the extent of database maintenance by different industrial sectors. It is observed from this Table that except for the chemicals and pharmaceutical sector industries, all others maintain engineering databases to a reasonable extent.

TABLE 1. TOTAL VALUE OF MACHINERY AS PERCENTAGE OF GROSS TURNOVER

Turnover (in million INR)	Category 1	Category 2
Up to 20	14.05	34.81
20-99	19.26	22.16
100-200	16.12	37.42
More than 200	12.88	39.97
Average	15.58	33.59

* 45 INR = 1USD

On the contrary, formulation databases are not maintained to any significant extent by any industrial sector. Although all the sectors maintain manufacturing databases, the percentage of firms maintaining such a database is indeed very high for the automobile sector (77.36%).

This sector exhibits a similar response regarding maintenance of inventory databases that otherwise are also maintained by engineering sector industries to a fair extent but not by chemicals/pharmaceuticals and electrical/electronics sector industries. Significantly, marketing databases are not maintained by automobiles and engineering sectors and these are maintained only to a limited extent by the other sectors.

Table 3 presents the design objectives of the firms (first choice objectives). It is found that for firms possessing a design department (category 1 firms), meeting unique demands of the customer is the predominant design objective (79.2%) whereas reliability (13.9%) is also important. For firms without a separate design department (category 2 firms), the predominant first choice design objective is meeting unique customer demands whereas minimum consumption of materials and resources, surpassing the features of competitors' products, ergonomics and ease of operation, optimality, and reliability are also relevant.

Table 4 presents the second choice design objectives. For the first category of firms, ensuring minimum consumption of materials and resources is the most important design objective. Other prominent design objectives for this category include ergonomics and ease of operation (21.0%), optimality (14.2%), and surpassing the features of competitors' products (14.2%). For category 2 firms, the prominent ones include ease of manufacturing, surpassing the features of competitors' products (that is, in fact common to both categories of firms), and minimum consumption of materials and resources but the most significant one is reliability (45%) of the designed product.

A. *Design and industrial innovation: Significance of networks*

Table 5 through Table 8 help illustrate the significance of networks in technological innovation. Aspects of design engineering as industrial innovation indicators do not act in isolation but linked with other relevant actors.

Table 5 presents the first choice sources of information for the design function. For category 1
firms, the marketing team is the most important source of information (60.7%) followed by dealers (32.2%). There are the only two prominent sources for this category of firms.

TABLE 2. DATABASE MAINTENANCE

Firm type	**Percentage of firms (Engineering)**	**Percentage of firms (Formulation)**	**Percentage of firms (Manufacturing)**	**Percentage of firms (Inventory)**	**Percentage of firms (marketing)**
Automobiles	66.03	22.64	77.36	77.36	33.96
Engineering	54.71	27.36	54.71	45.28	27.36
Chemicals/pharmaceuticals/ textiles	28.30	14.16	42.54	28.30	42.54
Electrical/electronics	66.03	0.0	55.56	22.64	44.54

TABLE 3. DESIGN OBJECTIVES (FIRST CHOICE)

Firm Category	**Meeting unique customer demands**	**Minimum consumption of materials/ Resources**	**Surpass the features of competitors' products**	**Ease of manufacture**	**Ergonomics and ease of operation.**	**Opti-mality**	**Reliabilit y**
Cat.1	79.2	0	0	0	6.9	0	13.9
Cat. 2	47	13	13	0	13	6.5	6.5

TABLE 4. DESIGN OBJECTIVES (SECOND CHOICE)

Firm Category	**Meeting unique customer demands**	**Minimum consumption of materials/ Resources**	**Surpass the features of competitors' products**	**Ease of manufacture**	**Ergonomics and ease of operation.**	**Opti-mality**	**Reliability**
Cat.1	7.4	28.5	14.2	7.4	21.0	14.2	7.4
Cat. 2	0	11	22	22	0	0	45

TABLE 5. SOURCES OF INFORMATION (FIRST CHOICE)

Firm Category	**Mkt. Team**	**Dealer s**	**Mkt. survey**	**Vendors**	**Service team**	**Joint venture/network partner**
Category 1	60.7	32.2	7.1	0	0	0
Category 2	37.7	13.2	5.7	18. 8	13.2	13.2

TABLE 6. SOURCES OF INFORMATION (SECOND CHOICE)

Firm Category	**Mkt. Team**	**Dealer s**	**Mkt. survey**	**Vendors**	**Service team**	**Joint venture/network partner**
Category 1	30.6	23.8	14.3	9.5	14.3	9.5
Category 2	13.6	27.3	13.6	9. 1	22.7	13.6

TABLE 7. WHETHER DESIGNING AGREEMENT/ARRANGEMENT WITH A NETWORKED PARTNER IS SIMULTANEOUS TO OTHER PARALLEL AGREEMENTS

Firm Category	**Marketing arrangement**	**Service/training arrangement**	**R&D arrangement**	**Design engineering arrangement**
Category 1	36.4	36.4	42.2	42.2
Category 2	5. 0	15. 0	15. 0	15. 0

TABLE 8. WHO GENERALLY PROVIDES THE SPECIFICATIONS AND ENGINEERS THE PROTOTYPES

Firm Category	**Joint venture partner/ technical collaborator s**	**Own design team/ other in-house team**	**Business associate/ partner**	**Engineering consultant**	**R&D consul-tant**	**Software consul-tant**	**Outsider**
Cat.1	8.3	75	25	25	16.6	16.6	32.3
Cat. 2	19	38.1	0. 0	4.8	4.8	0. 0	19

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For category 2 firms, this distribution is more widespread with marketing team (37.7%), dealers (13.2%), vendors/suppliers (18.8%), the service team (13.2%), and joint venture/network partner (13.2%) as important sources of information.

Table 6 presents the second choice sources of information for the design function. Regarding this second choice, the important ones both for category 1and 2 firms include the marketing team, the dealers, market surveys and the service team. The only additional sources of information of category 2 firms are the joint venture/network partners.

Table 7 displays what other agreements are simultaneous to a designing agreement or arrangement among firms and their network partners. The findings re-emphasize of a network approach for successful industrial innovation. For firms with a separate design department (category 1), the design agreements are often simultaneous to a marketing arrangement (36.4%), servicing/training arrangement (36.4%), R&D arrangement (42.2%), and design engineering arrangement (42.2%). For category 2 firms, all these arrangements (except marketing arrangement) are at times entered into but much less frequently (15%).

Illustrating this network approach further, Table 8 points out that among all the network partners of a firm, except for joint venture partner/technical collaborators, all others take part in the design of the prototypes for category 1 firms. For such firms, the in-house design departments are most of the time doing this job (75.0%), though there are other categories too like the business associates/partners (25.0%), the engineering consultants (25.0%), R&D or software consultants (16.6%), and even outsiders (32.3%). For category 2 firms as well, the prototypes are mostly designed in-house (38.1%) but this percentage is much lower than that for firms which do possess a separate design department. Others who design the prototypes include the joint venture partners/technological collaborators (19.0%), and outsiders (19.0%).

5. CONCLUSION

The study thus highlights the critical aspects of the design process as industrial innovation indicators. These results can be related to some other studies on different aspects of the design process. Reference could be made to the results of a study conducted in a medium-sized aerospace company according to which the percentage of time spent by engineers in different activities had a high component of documentation (28.5%), solving thinking (28.0%), support and consulting (17.1%), and information gathering (13.7%) [27]. In yet another study, it was shown that competitiveness of a manufactured product can be improved by (i) good product design; (ii) product innovation, and (iii) production process improvements [28]. Their study results have also shown that product design could affect both price competition through design for economic manufacture and low life-cycle costs, and non-price competition, either through the technical design of the product itself to improve performance, appearance, quality, etc., or by taking into account associated service-related non-price factors.

The results of our study, similarly, are in line with the findings of another empirical study carried out that has shown that two main strategic dimensions are related to success in technically designing new products [29]. The first is the R&D orientation of the firm and the second is the technology use. The data shows that regardless of industry, firms with more open cooperation with the outside research environment, that is more external R&D strategies, almost always have been more technically successful in designing new products. Network positioning, gaining access to external information and assistance by having wide and flexible contacts with the external environment was, therefore, one of the most strategic variables in their analysis. The results of our study corroborate the above and establish the significance of the network approach in formulating a design engineering policy for a firm that promotes industrial innovation.

The results of the study indicate that design engineering plays a critical role in fostering innovations in industrial firms. It highlights the role of developing suitable indicators to tap specific design engineering practices, the network linkages, and what all factors need to be looked into while initiating policy measures to promote industrial innovation in the manufacturing sectors. It has been observed, for instance, that majority of firms possessing a separate DD exhibit a better appreciation of what constitutes a successful innovation and follow it up by formulating design engineering agreements with a networked partner simultaneous to marketing, service or R&D arrangements. The results have implications for formulating policies that seek to promote industrial innovation and the incentive schemes that go along with it. Industrial innovation strategies in force at the national or local levels have largely overlooked the importance of design engineering in fostering industrial innovation and the process intricacies inherent in it. The present study aims to do just that. There is, therefore, a need for a more extensive empirical research on a larger sample size and spread over a larger geographical spread to further consolidate the insights gained from the present study.

6. REFERENCES

[1] P. Biegelbauer and S. Borras, Innovation Policies of Europe and US: The new Agenda, England: Ashgata Publishing, 2003.

[2] S. Borras, Innovation Policy of the EU: From Govt to Governance, UK: Edward Elgar, 2003.

[3] F. Malerba and S. Brusoni, Perspective on Innovation, London: Cambridge University Press, 2007.

[4] R. Roy and S. Potter, "The commercial impacts of investments in design," Design Studies, vol. 14(2), pp. 171-193, 1993.

[5] R. Roy, "Can the benefits of good design be quantifies?," Design Management Journal, vol. 5(2), pp. 9-17, 1994.

[6] S. Li and I.M. Boyle, "Engineering design: Perspectives, challenges, and recent advances," Journal of Engineering Design, vol. 20(1), pp. 7-19, 2009.

[7] K. Kalogerakis, C. Luthje, and C. Herstatt, "Developing innovations based on analogies: Experience from design and engineering consultants," Journal of Product Innovation Management, vol. 27, pp. 418-436, 2010.

]8] C. Freeman, The Economics of Hope: Essays on Technical Change, Economic Growth and the Environment, London: Frances Pinter, 1992.

[9] J.M. Utterback, Mastering the Dynamics of Innovation, Boston, MA: Harvard Business School Press, 1994.

[10] T. Peters, "Pundit of passion", Design, vol. Summer, pp. 18-19, 1995.

[11] J.C.X. Feng and A. Kusiak, A., "Data mining applications in engineering design, manufacturing and logistics: Guest editorial," International Journal of Production Research, vol. 44(14-15), pp. 2689-2694, 2006.

[12] F. Zirpoli and M.C. Becker, "The limits of design and engineering outsourcing: Performance integration and unfulfilled promises of modularity," R&D Management, vol. 41(1), pp. 21-43, 2011.

[13] W.D. Li. and Z.M. Qiu, "State-of-art technologies and methodologies for collaborative product development systems," International Journal of Production Research, vol. 44(13), pp. 2525-2559, 2006.

[14] S. Roy, "Technology transfer from R&D centres in India and development of industrial clusters," in Enterprise Support Systems: An International Perspective, M.J. Manimala, J. Mitra and V. Singh, Eds., ISBN: 978-81-7829-927-3, New Delhi: Sage, 2009, pp. 217-227.

[15] S. Roy and P. Banerjee, "Developing regional clusters in India: The role of national laboratories," International Journal of Technology Management and Sustainable Development, vol. 6(3), pp. 193-210, 2007.

[16] S. Roy, "Networking as a strategy for technology transfer and commercialization from R&D laboratories," Industry and Higher Education, vol. 20(2), pp. 123-133, 2006.

[17] S. Roy and P.K.J. Mohapatra, "Regional specialisation for technological innovation in R&D laboratories: A strategic perspective," Artificial Intelligence and Society, vol. 16, pp. 100-111, 2002.

[18] E. von Hippel, "Lead users: A source of novel product concepts," Management Science, vol. 32(7), pp. 791-805, 1986.

[19] C. Boks and A. Stevels, "Essential perspectives for design for environment: Experiences from the electronics industry," International Journal of Production Research, vol. 45(18-19), pp. 4021-4039, 2007.

[20] R.G. Cooper and E.J. Kleinschmidt, "New products: What separates winners from losers?," in Managing Innovation, J. Henry and D. Walker, Eds., Sage: London, 1991.

[21] S. Vinodh and D. Kuttalingam, "Computer aided design and engineering as enablers of agile manufacturing: A case study in an Indian manufacturing organization," Journal of Manufacturing Technology Management, vol. 22(3), pp. 405-418, 2011.

[22] P. Boonkanit and A. Kengpol, "The development and application of a decision support methodology for product eco-design: A study of engineering firms in Thailand," International Journal of Management, vol. 27(1), pp. 185-199, 2010.

[23] K.F. McCardle, "Information acquisition and the adoption of new technology," Management Science, vol. 31(11), pp. 1372-1389, 1985.

[24] J.W. Brown and J.M. Utterback, "Uncertainty and technical communication patterns," Management Science, vol. 31(3), pp. 301-311, 1985.

[25] J.R. Dixon and M.R. Duffey, "The neglect of engineering design," California Management Review, vol. 32(2), pp. 9-23, 1990.

[26] C. Spitas, "Analysis of systematic engineering design paradigms in industrial practice: A survey," Journal of Engineering Design, vol. 22(6), pp. 427-445, 2011.

[27] D. Luh, Y. Ko, and C. Ma, "A structural matrix-based modelling for designing product variety," Journal of Engineering Design, vol. 22(1), pp. 1-29, 2011.

[28] N. Williams, P.K. Kannan, and S. Azarm, "Retail channel structure impact on strategic engineering product design," Management Science, vol. 57(5), pp. 897-914, 2011.

[29] R. Keller, C.M. Eckert, and P.J. Clarkson, "Using an engineering change methodology to support conceptual design," Journal of Engineering Design, vol. 20(6), pp. 571-587, 2009.

[30] R.A. Crabtree, M.S. Fox, and N.K. Baid, "Case studies of coordination activities and problems in collaborative design," Research in Engineering Design, vol. 9**,** pp. 70-84, 1997.

[31] R. Roy and J.C. Riedel, "The role of design and innovation in competitive product development," Second European Academy of Design Conference: Contextual Design – Design in Contexts, Stockholm, Sweden, 23-25 April, 1997.

[32] H. Nystrom, "Company strategies for designing and marketing new products in the electrotechnical industry," in Design and Innovation: Policy and Management, R. Longdon and R. Rothwell, Eds., London: Frances Pinter, 1985, pp. 18-26.